Living With A Star
Abstracts of Selected Proposals
(NNH23ZDA001N-LWS)

Below are the abstracts of proposals selected for funding for the Living With A Star program. Principal Investigator (PI) name, institution, and proposal title are also included. Sixty-one proposals were received in response to this opportunity. On May 1, 2024, seventeen proposals were selected for funding.

Sam Califf/University Of Colorado, Boulder
Investigation of Charged Particle Dynamics in the Inner Magnetosphere Using a Data-driven Machine Learning Electric Field Model and a Global Magnetospheric Simulation

This proposal aims to develop a model of the inner magnetospheric quasi-static electric field using in-situ electric field data and machine learning, and to apply the electric field model to a global kinetic model to study the dynamics of energetic charged particles. Existing electric field models do not capture the observed enhanced electric field at low L shells, the MLT-dependence of the electric field, and/or the temporal variation of the electric field that has been demonstrated by in-situ observations. The overall science goal is to understand the temporal and spatial variability of the electric field in the inner magnetosphere and its effect on energetic charged particle dynamics. We plan to address the following science questions: (SQ1) What are the spatial and temporal characteristics of the electric field in the inner magnetosphere during geomagnetic storms and substorms? (SQ2) What role do temporal and spatial characteristics of the electric field play in the deep penetration ($L<4$) of 10s-100s keV electrons? (SQ3) To what extent does the electric field contribute to differential penetration depths for 100s keV electrons and protons in the inner magnetosphere?

We will address the science questions by developing an empirical electric field model based on in-situ double probe data from the Van Allen Probes and THEMIS using machine learning techniques. Time histories of solar wind measurements (e.g., velocity, density, magnetic field) and geomagnetic indices will be used as inputs to a neural network to predict the equatorial magnetospheric electric field as a function of L and MLT. The electric field data will be carefully examined to remove anomalies related to spacecraft charging and spacecraft vxB subtraction near perigee, and 3-d electric field estimates will be derived from Van Allen Probes data by assuming that there is no electric field along the magnetic field direction. Electric field measurements will be mapped to the magnetic equator. The model will reveal the spatial and temporal characteristics of the inner magnetospheric electric field under quiet-time, storm and substorm conditions contained in these long-term in-situ datasets.

We plan to incorporate the electric field model in the ring current-atmosphere interactions model with self-consistent magnetic field (RAM-SCB), which solves the kinetic bounce-averaged equations of energetic charged particles in the Earth's magnetosphere. RAM-

SCB includes terms to model the transport, acceleration, and loss processes of energetic particles in the inner magnetosphere and can be readily adapted to use new electric field models. Simulations of the dynamics of 10s to 100s keV electrons and protons will be performed and compared to Van Allen Probes observations to quantify the effect of the electric field on ring current and radiation belt particles.

This proposal will contribute to the broader goals of FST 2 by quantifying the global variability and reconfiguration of the electric field in the inner magnetosphere during storms and substorms. The electric field is a fundamental parameter that affects the transport of particle populations in the inner magnetosphere including the plasmasphere (~1 eV), ring current (~keV), and the radiation belt (~MeV) particles, and coupled interactions between these particle populations are important drivers of the global dynamics of the magnetosphere. Our model will improve the predictive capabilities of the radiation and spacecraft-charging environment by better representing the spatial and temporal characteristics of the electric field. The model can also be used in other investigations in the FST either directly in simulations as a more accurate empirical electric field model or as an empirical reference for comparison to self-consistent electric field models, and has potential applications for assimilating various types of observations to reconstruct state of the global magnetosphere.

Bin Chen/New Jersey Institute Of Technology

Evolution of Magnetic Field and Nonthermal Electrons of CMEs and CME-Driven Shocks from Low to Middle Corona

Coronal mass ejections (CMEs) are a major driver of space weather. It is essential to understand how they evolve as they propagate from the Sun into the heliosphere. While progress has been made over the past decades, significant challenges remain in obtaining a comprehensive understanding of the evolution of CMEs and the often associated shocks. In particular, the magnetic field, nonthermal particles, and shocks associated with CMEs in the near-Sun corona remain poorly constrained. Hence, developing remote-sensing techniques and suitable datasets to constrain these crucial properties of CMEs is extremely important and timely. While it has been long recognized that radio emission from CMEs can serve as a unique technique to diagnose the magnetic field and nonthermal electrons entrained in CMEs as well as CME-driven shocks, its usage has been limited due to the lack of sensitive, high-dynamic-range imaging spectroscopy observations. Recently, with the advent of the Owens Valley Long Wavelength Array (OVRO-LWA), a newly commissioned radio array of hundreds of antennas, this has become a reality in the meter-decameter wavelength range. OVRO-LWA consists of 352 dipoles spread within an area of diameter 2.5 km. The presence of this large number of antennas within a small area ensures that the spectroscopic snapshot point spread function is exquisite, thus allowing very high dynamic range snapshot imaging spectroscopy. The different observing modes of OVRO-LWA operate simultaneously, allowing us to track a variety of solar phenomena over a large range of spectral and temporal scales at varying surface brightness sensitivities. These newly available datasets are well suited to analyze radio emissions from CMEs in the low to middle corona, which perfectly complements the existing white light and EUV data and numerical modeling to form a more comprehensive physical picture of CME initiation and evolution. Buoyed by this advancement, we propose to combine white light coronagraph data from instruments including SOHO/LASCO, STEREO/COR, and EUV imaging data from SDO/AIA, GOES-R/SUVI, STEREO/EUVI, with new radio imaging spectroscopy data from OVRO-LWA to perform a detailed study of CME initiation and evolution, with a focus on its magnetic field, nonthermal electrons, and CME-driven shocks. We aim to address the following main questions:

- How does the magnetic field of a CME vary spatially and temporally as it propagates from the Sun into the middle corona?
- How do the nonthermal electrons, both accelerated at the CME shock and trapped inside the CME, evolve with time and space?
- Where and how do CME-driven shocks form and evolve?

Our proposal directly addresses FST #3, "Evolution of Coronal Mass Ejections in the Corona and Inner Heliosphere." Our proposed study will also have a strong contribution to the Focused Science Team's effort. The derived magnetic field, nonthermal electron distribution, and shock properties will complement the plasma diagnostics from the multi-wavelength EUV and white light data. They will also provide new and unique inputs to form the observational basis for CME modeling. Our focused study of CMEs from the solar surface to the middle corona will also complement other studies that address CME evolution in the upper corona and interplanetary space.

Christine Gabrielse/The Aerospace Corporation
Conductivity Across Space and Time as Informed by Particle Precipitation

This proposal addresses the NASA Living With a Star Focused Science Topic (FST) 1: Understanding Ionospheric Conductivity and its Variability. The FST1 science goal is to advance understanding of ionospheric conductivity variations that can inform empirical models or first-principle physics-based models used to specify and/or predict ionospheric impacts of space weather. Another key objective of FST1 is to contribute quantitative assessments of spatiotemporal variations in conductivity driven by high latitude energetic electron precipitation. We focus on the contribution to conductivity by precipitating electrons that result in the aurora across multiple scale sizes and temporal scales.

Our methodology relies on a mosaic of all-sky-imagers (ASIs), currently the only dataset that can measure energy flux and mean energy inputs to determine conductance across space (in latitude & longitude) over long timescales (hours). NASA's THEMIS mission includes an array of 20 ASIs that monitors the majority of the nightside auroral oval at a 3 second cadence and up to 1 km resolution, providing a large-scale view at temporal and spatial resolutions required to study the aurora on meso-scales (10s to 100s km wide). These data, combined with other ground-based assets like incoherent scatter radar (ISR), meridian scanning photometers (MSPs), and redline all-sky-imagers (from Geospace Observatory Canada), will be used to improve the particle precipitation description. This improved particle precipitation data will be used with models including the Boltzmann

Three Constituent (B3C) auroral transport code and GLobal airglOW (GLOW) to answer the following science questions:
1. How does high latitude conductivity vary over space and time throughout a substorm?
2. How does high latitude conductivity vary over space and time throughout a weak storm (CIR vs CME; Main phase vs. recovery phase)?
3. Which spatiotemporal scales are most important in high latitude conductivity variability?

To obtain 3D altitudinal conductivity profiles over time, we will use the energy flux and mean energy values from the ASIs as inputs to the B3C auroral transport code and the GLOW model. To analyze that data product, we will plot the peak conductivity & its altitude in 2D over time. We will also plot the conductance over 2D for the total region (>90 km) as well as for the E-region (90-150km) and F-region (>150 km) separately, demonstrating the most important region for conductivity. We will plot spatial scale results for different modes of response to determine how different driving can affect ionospheric response. We will also determine where within the auroral oval strong mesoscale conductance enhancements typically occur and estimate their lifetime over a specific location. Our plan to determine uncertainties includes utilizing conjugate DMSP/SUSSI measurements, MSPs, and ISRs to compare to our ASI-determined energy flux, mean energy, and conductance/conductivity.

The proposed investigation directly addresses the science goal of this FST, as our work will provide event-specific multi-scale conductivities in the nightside high-latitude ionosphere and answer how conductivity varies during storms and substorms. We will address two of the types of investigations listed in the AO: 1) improve the particle precipitation description on the three-dimensional conductivity structure, which will 2) lead to the development of numerical methods and/or models to improve representation of ionospheric conductivity and impact on ionosphere-magnetosphere coupling processes. Our results will be invaluable to the rest of the LWS team, as our products can inform/provide inputs to models that other LWS team members bring to the table. Other LWS team members may use our values to obtain conductivity profiles with their models, which can be cross-compared. Our conductivity profiles could also be used by teams with an AI or ML component capable of ingesting the large 3D dataset.

Jesper Gjerloev/Johns Hopkins University
ARCH - Bridging the gap between data and insight

The proposed project is directly addressing LWS FST 1:
Goal 1: Determine the response of ionospheric conductance distribution to: 1) changes the solar wind pressure, and, 2) southward turnings of the IMF;
Goal 2: Determine the relative importance of conductances and convection electric field during different unloading events (e.g. substorms);
Goal 3: Provide decades of self-consistent electromagnetic solutions for the auroral ionosphere at a 2-min temporal resolution (including Hall and Pedersen conductances).

The ionospheric conductance distribution is a fundamental electrodynamic parameter but the characteristics remain poorly understood. While we have decades of electric potential distributions the observational difficulties have led to far less information about the conductances. One approach is to derive the conductances from either imaging or measured particle precipitation (particle approach) while the other is using measured fields to derive the conductances in a self-consistent manner (field approach). In this proposal we will use the latter since the combination of AMPERE, SuperDARN and SuperMAG allows for decades of global, continuous, electrodynamic solutions. Such a comprehensive dataset is truly the holy grail of the Magnetosphere-Ionosphere (M-I) community.

Goal 1 we will identify abrupt changes in the solar wind pressure and well-defined abrupt southward turning of the IMF to determine how the ionospheric conductances evolve following such events. We expect the a local time dependence of the response (e.g. nightside and dayside) and thus this objective requires continuous global conductance distributions. With the availability of decades of conductance distributions we will have a rice dataset to provide robust statistical results.

Goal 2 will include isolated substorms and steady magnetospheric convection events to determine how the convection electric field and the conductances evolve as the event develop. E.g. what is the relative changes to the conductances and electric field within the substorm bulge vs outside the bulge? Likewise for the steady convection events. The findings will provide constrains on the driver or driver of the electrojet segments. As for Goal 1 we will have a rich event database to ensure closure.

Goal 3 utilizes three well-established services, AMPERE, SuperDARN and SuperMAG, to derive first-principle solutions. Success is highly likely since it is based upon an existing infrastructure developed under a previously funded NSF EarthCube project. Formalism and implementation was proven under that grant while optimizations, validation and release of solutions will be done under this project. The uniformly gridded solutions covering the entire high latitude northern ionosphere has the spatiotemporal resolution needed to address Goals 1 and 2. It will, further, be a treasure trove for the M-I community to be utilized in a long list of studies and it also provides constrains for global MHD simulations as well as much needed magnetospheric input to the WACCM-X simulations. Finally, the uniformly gridded, regularly time separated, and easy to access solutions will serve the machine learning community.

In summary, the proposed study:

- directly addresses the LWS FST #1;
- is relevant to the LWS program goal #2, which is to understand how the Earth and planetary systems respond to dynamic external and internal drivers;
- achieving the three goals applies to storm time conditions since goals 1 & 2 provide understanding of processes and goal 3 enable the wider community to perform a wide range of storm time studies;
- provides the community with a much needed comprehensive set of ionospheric solutions;
- is highly likely to succeed since a proof of concept have been developed;
- the team has hundreds of publications on relevant topics and has developed and operated similar data services.

Brian Harding/University of California, Berkeley

Kinetic and photochemical modeling of conductivity depletions in the subauroral region

To advance our understanding of magnetosphere-ionosphere (M-I) coupling processes, it is crucial to investigate how ionospheric conductivity responds to various drivers. While robust models already exist to characterize the impact of particle precipitation on conductivity, there is a significant gap in our ability to evaluate the consequences of currents and electric fields. To address this, we propose to develop, test, and exercise a research-level code which combines existing electrostatic, kinetic, and chemical models to quantify the impacts of electromagnetic drivers on ionospheric conductivity. The subauroral ionosphere, characterized by extreme electrodynamic drivers such as subauroral polarization streams (SAPS) and subauroral ion drifts (SAIDs), serves as a natural laboratory for disentangling the influence of electromagnetic drivers from particle precipitation.

While the connection between conductivity enhancements, optical signals, and M-I coupling mechanisms related to auroral precipitation is well-established, the subauroral region presents intriguing questions about the relationship between conductivity variations (especially depletions) and optical phenomena like stable auroral red (SAR) arcs, strong thermal emission velocity enhancements (STEVEs), and the picket fence. No existing models self-consistently capture the interplay of non-Maxwellian electron processes, the electric fields that drive them, and the subsequent neutral chemistry governing conductivity depletions and emissions.

The science questions are: (SQ1) How do extreme field-aligned currents and electric fields imposed by the magnetosphere modify ionospheric conductivity? (SQ2) What optical signatures are tracers of these processes? Answering SQ1 will advance our knowledge regarding how conductivity is influenced by magnetospheric electromagnetic inputs, which are less well understood compared to particle inputs. SQ2 will advance our knowledge of the relationship between optical signals and the M-I coupling signatures responsible for conductivity depletions, enabling ground-based optical observations of conductivity.

The methodology comprises adapting and combining 3 existing models for electrostatic, kinetic, and chemical calculations. This coupled model will capture the time evolution of the conductivity profile driven by magnetospheric electric fields and currents. It will be validated using an existing database of Swarm/DMSP overflights. The model will then be used to study the causes and optical signatures of conductivity depletions. Swarm/DMSP observations will be used to define a parameter space of upper-boundary electric-field and current drivers. This space will be swept to determine how conductivity depletions depend on electromagnetic inputs. Mechanism studies will then be conducted, wherein certain processes, like the vibrational excitation of nitrogen by superthermal electrons, will be turned on and off. This will provide closure on SQ1. An analogous study will then be conducted where visible emissions are monitored, to determine their relationship to conductivity depletions and potential uses as proxies thereof. This will provide closure on

SQ2. The proposed methodology, primarily focused on studying conductivity depletions and their associated optical emissions, is anticipated to yield additional insights into specific processes, such as the mechanisms behind SAR arc, STEVE, and picket fence emissions.

This proposal is directly relevant to both stated objectives of FST#1, as it (1) quantitatively assesses variations in conductivity driven by currents and electric fields and (2) assesses the degree to which changes in conductivity are related to optical signals. Comprehensive models capturing all relevant emission physics will be useful for team members who will use emissions to estimate conductivity. Also, our models could serve as post-processors or be two-way coupled into global/regional MHD models produced by the team.

Michael Henderson/Los Alamos National Laboratory

Understanding Storm-Time Systems Interactions in the Inner Magnetosphere using ML-Assisted Modeling, Global Imaging, and In-Situ Observations

In recent years, a number of new and poorly understood phenomena have been discovered in the Earth's magnetosphere and ionosphere. These include: meso-scale structuring of the ring current; formation of structured "Sub-Auroral Polarization Streams" or SAPS; "detaching SAR arcs" and their evolution into other auroral forms like classical SAR arcs and STEVE (Strong Thermal Emission Velocity Enhancement) emissions.

Structuring of the ring current has become more evident in recent years due to the adoption of higher fidelity ring current indices that have higher temporal resolution than Dst (and are also capable of monitoring symmetries/asymmetries in multiple magnetic field components) and it is thought that meso-scale earthward flows may be responsible.

Sub-Auroral Polarization Streams (SAPS) are very strong anomalous plasma flows (in both the ionosphere and the magnetosphere) that often develop just equatorward of intense auroral displays on the dusk to pre-midnight sector -- especially during storms. They have been observed since the 1990s, and have been linked to a complex magnetosphere-ionosphere (MI) coupling feedback mechanism that involves the inward motion of the ring current ions across the duskside cold plasmasphere region and are sometimes observed to occur together with the production of "Giant Undulations" (GUs) in the equatorward boundary of the auroral oval in this region. However, SAPS have only recently been firmly connected to the occurrence of complex meso-scale particle injections from the magnetotail. And, although their impact on the coupled MI system is thought to be extremely important, at present they are both poorly understood and under-represented in current ring-current/inner-magnetosphere models.

Detaching SAR arcs were recently discovered in ground-based All Sky Imagers as rapidly equatorward-moving bands of auroral emissions that break away from the main auroral distribution during disturbed conditions. The first observations showing this behavior in a global context were recently presented using global auroral imagery from the NASA POLAR spacecraft and it was demonstrated that the development of detaching SAR arcs is preceded by the occurrence of intense auroral streamer activity which is a firmly established proxy for meso-scale flows impacting the inner magnetosphere.

In addition, new observations have shown that SAR arcs can also morph into another very recently discovered feature called STEVE and it is thought that meso-scale particle injection dynamics may be responsible for these as well. New observations have also shown for the first time that GUs and STEVE-like emissions can develop adjacent to one another following intense auroral streamer activity.

All of these poorly understood phenomenon can potentially be explained with a recently proposed model whereby the ion plasmasheet/ring current is dynamically pushed Earthward of the electron plasma sheet which then leads to the development of GUs (and potentially the disruption of the plasmapause). We propose to modify the RAM/SCB ring current model to include the appropriate missing physics in order to test this hypothesis. The modified code will have higher spatial resolution and will run with diffusion coefficients obtained via machine-learning (ML) techniques. The ability to image the dynamics using global auroral imagery provides us with an extremely powerful way to test and constrain models of the inner magnetosphere. We will also use global imagery to validate and constrain the ring current model.

Lynn Kistler/University of New Hampshire, Durham

Determination of the Global Hot Plasma Distribution During Geomagnetic Storms

The main cause of the geomagnetic disturbance that defines a geomagnetic storm is the development of the ring current, created by increased particle pressure in the inner magnetosphere. One of the key features of the storm-time ring current is the enhancement of the ionospheric contribution to the plasma, identified by the heavy ions. The enhanced role of ionospheric-origin heavy ions throughout the magnetosphere that culminates in the strong ring current is a key storm-time global system-level change. The enhanced heavy ions have dynamic effects, changing the reconnection rate, affecting wave excitation, and contributing significantly to the ring current development. Predicting the changes in the spatial distributions of the different plasma species throughout the magnetosphere is key to understanding the development of geomagnetic storms, but how the distribution of the plasma, and particularly the ionospheric heavy ions, change globally as a function of time during a storm cannot yet be fully characterized or predicted.

Over the last 20 years, there have been a set of instruments on different spacecraft that have similar characteristics: moderate mass resolution (separating at least H+, He+, and the O+/N+ group), good time resolution (4-20 s), and an energy range that covers the bulk hot plasma (~10 eV-50 keV). Together, these measurements provide comprehensive coverage of the composition of the magnetospheric plasma that can be used to trace the particles that form the ring current.

This study objective: "To determine how the global contribution of ionospheric O+ changes as a response to solar wind drivers, on storm and substorm timescales" is addressed by focusing on three questions:

How does the contribution of different species to the ring current change?

How does the H+ and O+ ionospheric outflow from the auroral regions change?

When and where does the ionospheric outflow contribution to the nightside plasma sheet change?

To address the questions, we will use neutral networks driven by a combination of solar wind parameters and geomagnetic indices to characterize the different regions. For the first question, the contributions to the ring current of the species H+, O+ and electrons will be determined using the Van Allen Probes and Arase data sets. The full pressure and individual energies will be modeled. For the second question, the FAST TEAMS dataset is used to show how the ion outflow varies with solar wind parameters. For the third question, the H+ and O+ densities and pressure in the plasma sheet further down-tail will be characterized using the MMS and Cluster datasets to capture the changes before and during a storm, showing where and when the ionospheric ions reach the plasma sheet. The combination of these studies will show how the global contribution of ionospheric O+ changes as a response to solar wind drivers.

This study will contribute to the FST by showing the global changes in the ionospheric heavy ion contribution based on in situ measurements. The inclusion of electrons in the ring current model is also important for characterizing the environment relevant for spacecraft charging, as well as for determining the full pressure. The auroral outflow parameterization can be used as an input to global transport models. The results in the plasma sheet and ring current can be compared against other methods including global ENA images and global physical simulations, resulting in a true synergistic view of the global magnetosphere.

Noe Lugaz/University of New Hampshire

The Sheath and Duration of Coronal Mass Ejections: Multi-Spacecraft Studies

We propose to investigate the development of the sheath regions of coronal mass ejections (CMEs) during their interplanetary propagation, and the resulting properties of the sheath regions as well as the duration/size of CMEs, especially that of the magnetic ejecta part which may have enhanced and steady magnetic fields driving geomagnetic storms. About 80% of magnetic ejecta measured at 1 AU are preceded by a dense sheath, and for ~55% of all events, there is a fast-forward shock ahead of the sheath. The sheath region carries the majority of the CME mass, and is the region with the highest dynamic pressure of the entire CME structure. Investigating CME sheath regions is therefore critical to understand the solar wind-magnetosphere coupling during CME times, with sheaths resulting in large compression of Earth's magnetosphere and impacts on Earth's radiation belts. In addition, sheath regions can be directly imaged by coronagraphs and heliospheric imagers, which makes it possible to forecast the sheath region of CMEs before impact at L1. Similarly, the duration of a CME can be quantified from remote

observations and is a key parameter to determine how long Earth's magnetosphere will be under disturbed solar wind conditions and to forecast the magnitude of the magnetic field strength inside CME at 1 AU. Our key science objective is to understand how the CME propagation affects the presence and properties of the sheath region at 1 AU and the duration of the CME, and their variability on moderate scales. To do so, we address the following science questions:
1- How can the presence/absence, size and properties (density, magnetic field, temperature and velocity of the plasma within the sheath) of the sheath region near 1 AU be understood in terms of the CME propagation from the Sun to the in-situ spacecraft?
2- How do CME properties, especially duration/size and sheath properties, vary on moderate scales (0.3-10° or ~0.005- 0.17 AU in arc length) and/or in the last few hours before impacting Earth and how does this limit our forecasting capability?
3- Can the duration of a CME at 1 AU be forecasted from remote observations or measurements closer to the Sun than L1?
Methodology:
In order to answer the science questions, we primarily rely on (a) remote heliospheric observations by STEREO/SECCHI, SolOHI (when available) and PSP/WISPR (when available), and (b) in-situ measurements close to the Sun by PSP and SolO, especially during conjunction with assets at L1 or near 1 AU (STEREO-A). To investigate the variations of the CME and sheath properties on moderate scales, we also propose to study all events measured by STEREO-A and L1 as STEREO-A approaches the Sun-Earth line including all of 2022 (and magnetic field measurements at least to June 2023), as well as measurements of CMEs during time periods when spacecraft at L1 (Wind, ACE, DSCOVR) are separated by at least 0.005 AU.
Relevance to FST:
The proposed work is directly relevant to FST#3. It combines remote and in-situ data to understand CME propagation and the resulting structure. In particular, it focuses on "understanding the evolution of CMEs and their substructures" and "integrat[e] new combinations of observations to extract additional physical information about the evolution of CMEs and their substructures." This project also advances NASA LWS program goal "Understand how and in what ways dynamic space environments affect human and robotic exploration activities".

Dogacan Ozturk/University Of Alaska, Fairbanks
Investigating the role of high and low energy precipitation on ionospheric conductivity

Ionospheric conductance and conductivity determine how magnetospheric energy is dissipated through the Ionosphere. Their characterizations in numerical models mainly depend on using solar EUV and particle precipitation as boundary conditions. The particle precipitation is described by empirical estimates mostly utilizing the Defense Meteorological Satellite Program (DMSP) data. The energy range for these measurements is 32 eV - 30 keV in electron flux, which omits the high energy tail of diffuse aurora. Various studies have demonstrated the importance of high-energy precipitation for understanding lower thermospheric dynamics such as studies on NOx production and transportation, CO2 emission, and large-scale travelling atmospheric and

ionospheric disturbances (TADs and TIDs). In addition, the numerical implementations do not always account for the lower energy portion of the energy distribution (e.g., polar rain and <1 keV) and hemispheric variations that are necessary to accurately capture ion-neutral dynamics. Lastly, there is an interlinked relationship between convection electric fields and precipitation, as Joule heating affects the density and transport of different constituents that are important for determining conductivity profiles. This further necessitates the thorough exploration of ionospheric conductivity, with realistic electric fields and precipitating particle profiles. The team proposes three thrusts for this proposal to address the role of low- and high-energy particles on ionospheric conductivity by seeking the answers to the following science questions:
1. What is the contribution of high-energy particle precipitation (>30 keV) on ionospheric conductance and conductivity?
2. What is the role of low energy particle precipitation on the F-region density and how does this contribute to ionospheric conductivity/conductance affecting the global polar cap dynamics?
3. How much variability do multi-scale electric fields generate on ionospheric conductance and conductivity through heating and transport?

To conduct the proposed investigations, the team will primarily use the Global Ionosphere Thermosphere Model (GITM), which is a 3D general circulation model (GCM) that can resolve particle energies up to 500 keV. The high-resolution electric fields will be obtained from Assimilative Mapping of Ionospheric Electrodynamics (AMIE) and Assimilative Mapping of Geospace Observations (AMGeO) methods. These maps ingest multiple data sources like SuperMAG, SuperDARN, DMSP, and IRIDIUM. The conductance profiles from GITM and AMIE/AMGeO maps will be studied for assessing uncertainties. To verify the newly added chemistry for NOx and CO2, GITM results will be compared with the Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension (WACCM-X) model. The team will make use of Madrigal TEC, NASA AIRS (for CO2 related high-energy aurora), TIMED/GUVI and FUV data to study large-scale TADs and TIDs, and auroral events. When available, PFISR and RISR data will be used to obtain energy profiles of precipitating particles and validate the results. High-latitude Input for Meso-scale Electrodynamics add-on will be enabled to incorporate ISR data. These investigations will significantly improve the ionospheric conductivity modeling in GCMs.

This proposal brings together different aspects of the I-T modeling to tackle one of the most critical problems in understanding the coupled M-I-T system, ionospheric conductivity. The proposed efforts are highly relevant to the FST on Understanding Ionospheric Conductivity and its Variability" by exploring high and low tails of precipitating particle energies and coupling with the thermosphere and mesosphere region. The proposed investigations will help bridge various topics by supporting FST teams with 3D I-T parameters. The findings of the study will have strong implications for the upcoming NASA and ESA missions like EZIE, TRACERS, GDC, DYNAMIC, and Daedalus.

Elena Provornikova/Applied Physics Laboratory Johns Hopkins University

Coronal Mass Ejections from Sun to Earth: Understanding Evolution and Substructures through Simulations and Observations

Science Goals and Objectives.

Recent white-light imaging observations from Parker Solar Probe and Solar Orbiter, which observe CMEs at close proximity, have revealed an abundance of internal structures within CMEs. The relationship between these structures, the large-scale CME flux rope, the eruption process in the corona, and interactions with background solar wind streams all remain open questions. Additionally, structures embedded in CMEs can contribute to CME geoeffectiveness. The recent data motivate us to integrate high-resolution physics-based modeling tools capable of resolving these structures and observations to address the compelling questions on the multi-scale evolution of CMEs.

The overarching goal of the proposed project is to understand the physical processes shaping the structure of interplanetary CME, including flux ropes with substructures, sheath, and shock, by characterizing CME evolution in the solar corona and subsequent interaction with the solar wind in the inner heliosphere. To that end, we will utilize a combination of remote-sensing and in-situ data from different locations in the inner heliosphere and a coupling of a global coronal model with the CME initiation and a heliospheric model. In particular, we will address the following science questions:

SQ#1: How does the process of flux rope formation in the solar corona impact the magnetic properties of CMEs in the inner heliosphere?

SQ#2: How much of the substructures within ICMEs at mesoscales is attributed to the CME's evolution in the solar corona, as opposed to its interaction with the background solar wind?

SQ#3: What is the role of mesoscale structures that evolve within the CME and develop due to CME-solar wind interaction in creating geoeffective conditions at Earth?

Methodology.

Our investigation will have the following interweaving components:

Multi-scale CME modeling. We will couple two physics-based models, the solar corona with the eruption and evolution of a CME and the inner heliosphere. The coronal and heliospheric models have a demonstrated capability to resolve the relevant scales required for investigating the evolution of CMEs, including their substructures.

Data analysis. We will select CME events with imaging and in-situ observations by multiple observatories, including Parker Solar Probe and Solar Orbiter, providing detailed CME images. We will extract information about the CME magnetic structure, shape, internal features, and distortions. Observations will inform our modeling settings and scenarios. The model validation will be performed on the selected well-observed and well-understood CME events.

Geoeffectiveness. From the high-resolution simulations, we will analyze ICME geoeffectiveness depending on a path sampled through an ICME. We will characterize variations of quantities relevant to space weather due to the presence of smaller-scale structures and asses their contributions to an ICME geoeffectiveness. We will analyze variations of a CME shock strength and inclination, effects of CME deformations on the CME time-of-arrival, and variations across the CME sheath.

Relevance and contributions to Focused Science Topic (FST). This work contributes to the primary goal of FST#3 in several aspects: high-resolution modeling of CMEs from Sun to Earth advances our understanding of CMEs and CME evolution as well as improves existing modeling capabilities in the community; study of CME deformations at global and mesoscales directly responds to advancing our understanding of space weather impacts of CMEs. Beyond direct contribution to the FST primary goals and investigations, this work will also complement the broader FST team effort by providing high-resolution simulations of CMEs, synthesized white-light images, and CME reconstructions from imaging data.

Nishtha Sachdeva/University Of Michigan, Ann Arbor

Magnetic Evolution of Complex Coronal Mass Ejection Structures in the Solar Wind

Science Objectives and Goals:
Coronal mass ejections (CMEs) are known to be major drivers of geospace activity. The intensity of their impact is significantly affected by the complex interactions that CMEs undergo as they travel through the interplanetary medium. Physical processes affecting CMEs include reconnection with the background fields, which leads to flux erosion. Also, deflection, and rotation can impact the direction and strength of the propagating transient. Together, these affects combine to change the speed, mass density, and magnetic fields that may impinge on the Earth's magnetosphere causing various degrees of geomagnetic storms.
We propose to study the complex magnetic structures of CMEs as they evolve while interacting (and reconnecting) with the solar wind by investigating the evolution of different flux-rope configurations in background plasma. Our main science goals (SG) are:
SG1 - Identify and quantify the magnetic flux erosion due to solar wind-CME interaction driven by different flux-rope configurations in the solar corona and the inner heliosphere.
SG2 - Characterize the evolution of CME properties as they propagate through large scale magnetic structure of the solar wind, including flux rope deflection and rotation.
Methodology:
To achieve these goals, we will use state-of-the-art modeling tools to simulate the solar wind background and model the CMEs through the solar corona and inner heliosphere. The well established Alfven Wave Solar atmosphere Model (AWSoM) along with the Eruptive Event Generator (EEG) module within the Space Weather Modeling Framework (SWMF) will be used to model the solar wind and launch CMEs. The proposed work will employ three key flux-rope eruption models namely, the Gibson-Low (GL), Titov-D emoulin (TD) flux-ropes and the sheared arcades formed by helicity injection, STITCH (STatistical InjecTion of condensed Helicity). The model framework is capable of resolving small scale sub-structures to identify reconnection regions using the Adaptive Mesh Refinement (AMR).
Observations from STEREO, SOHO, PSP and SOLO (where available), Wind and ACE will be used to identify solar eruptions and characterize their propagation in various coronal and heliospheric regimes. Both remote (white-light, EUV) and in-situ (plasma

speed, density, magnetic field) data will be utilized and interpreted using synthetic outputs from numerical modeling. Observations will be used to verify and validate the simulated events as well as derive quantitative comparisons between the numerical data and observable features of flux erosion, reconnection, and evolution in the solar corona and inner heliosphere. The expertise of the team is very well suited to use the available methodology and data for this study.
Relevance:
The proposed work is highly relevant to the Focused Science Topic 3 (FST 3) - Evolution of CMEs in the Corona and Inner Heliosphere". The scientific goals outlined in this work are aligned with the overarching goals of FST3 to advance our understanding of CMEs, CME evolution, and space weather impact of CMEs as well as to improve heliospheric models, data analysis, and assimilation techniques within 1 AU heliocentric scales". The proposed work will contribute significantly to the Focused Science Team's efforts of studying the evolution of flux-rope structures and sub-structures and identifying the physical characteristics of CME evolution in solar wind plasma. This work builds upon public tools we have made available for runs on request at CCMC.

Viacheslav Sadykov/Georgia State University
Intertwining Physics-Based CME Modeling and Machine Learning for L1 Prediction of Interplanetary Magnetic Field

Investigating solar eruptions and their impact on the geomagnetic environment is among the most intriguing and important questions of space weather. While the expertise in the modeling of the coronal mass ejections (CMEs) and their propagation in the solar wind exists for more than one decade, the modeling approaches do not put constraints on the properties of the magnetic field of the CME when observed close to the Sun and, therefore, cannot assess its strength, direction, and dynamics at the L1 point later. Recent works have shown that the magnetic field configurations in the solar active regions (ARs) parental to the eruptions are connected to the magnetic field properties of the eruption at L1, identifying possibilities to constrain the latter. The Science Goal is to investigate the relations between the Bz component of the interplanetary magnetic field, the near-Sun properties of the eruption, and the properties of solar ARs, leading to the capabilities for improved forecasting of Bz and other plasma properties at L1. Our objectives are:
1) To investigate the inverse relationship between the properties of the interplanetary CMEs at L1 and their initiation parameters near the Sun using the grid of the GAMERA-Helio simulations and Gibson-Low (GL) flux rope model for the CME initiation;
2) To perform a detailed modeling of the several tens of CME events observed in situ at L1 and in white light near the Sun by utilizing the WSA and GAMERA-Helio simulations with the initial guess guided by inverse ML model;
3) To construct empirical relationships between the properties of the ARs parental to the modeled CMEs (related to magnetic fields, flare ribbons, and Hα filaments) and GL parameters of the CME and related uncertainties;
4) To develop a proof-of-concept ML surrogate model for forecasting the Bz and other plasma properties at L1 using an extended GAMERA-Helio grid, WSA-based boundary

conditions, and GL parameters manually constrained based on AR and coronagraph observations.
Methodology:
The investigation utilizes a combination of the WSA and GAMERA-Helio models. The WSA model is a combined empirical and physics-based model of the corona and solar wind which uses observations of the Sun's surface magnetic field and provides the radial magnetic field and solar wind speed at the outer coronal boundary surface. GAMERA is an MHD solver for modeling diverse magnetized plasmas. The heliospheric application of the code is currently used to model the steady-state solar wind in the inner heliosphere and the propagation and evolution of the interplanetary CME with internal magnetic structure.
The investigation will utilize the data from the ACE and DSCOVR in-situ observations of the solar wind plasma, SOHO/LASCO and STEREO/SECCHI coronagraph observations, and SDO/HMI observations of the photospheric magnetic fields in ARs. The semi-automated fitting tools will be utilized to constrain the parameters of the CME based on coronagraph observations.
Neural networks will be utilized to establish connections between the CME properties near the Sun and plasma properties at L1 and to connect the magnetic field properties in ARs and magnetic field-related Gibson-low parameters of the CME.
Relevance to LWS FSTs:
The proposal is targeted at the enhancement of understanding of CME evolution and of the prediction of the CME-related interplanetary magnetic field at the L1 point which is critical for advancing the prediction of geomagnetic impact. Therefore, the proposed investigation is directly relevant to the objectives of the LWS FWT #3 to advance our understanding of CMEs, CME evolution, and space weather impact of CMEs as well as to improve heliospheric models, data analysis, and assimilation techniques, within 1 AU heliocentric scales". Specifically, it helps FST #3 with respect to constraining the magnetic field properties of the CMEs near the Sun and at the L1 point and advancing the prediction of the related observables.

Cornelius Csar Jude Salinas/University of Maryland Baltimore County
Investigation of Global Ionospheric Conductivity Variabilities driven by E-region electron density

Ionospheric conductivity is a fundamental parameter, and its variability is important for ionospheric electrodynamics because it affects ionospheric currents that couple various regions of the global ionosphere. Currently, global-scale estimates of conductivity are only from empirical or first-principles Physics-based models. One of the main parameters needed to estimate conductivity is electron density (Ne). Unfortunately, the ionospheric E-region is a region where first-principles Physics-based model simulations of Ne are poorly constrained by observations. This is because of the lack of Ne observations in this region. Recently though, Wu et al [2022] retrieved multi-decade E-region Ne from Global Navigation Satellite System Radio Occultation (GNSS RO) missions. From these Ne profiles, Salinas et al [in preparation] developed an empirical model called E-region Prompt Radio Occultation Based Electron Density (E-PROBED), that accounts for photoionization and its dependence on the solar zenith angle and solar cycle phase. Thus, this proposed work aims to take advantage of these GNSS RO Ne profiles as well as E-PROBED to quantify the role of uncertainties in E-region Ne on simulated monthly-mean conductivity under geomagnetically quiet conditions. This proposed work quantifies errors in conductivity simulated by the Thermosphere Ionosphere Electrodynamics -- General Circulation Model (TIE-GM). TIE-GCM is a well-known and often used community climate model. The community frequently uses it or compares other models to it. To achieve this objective, we will first use ground-based observations and GNSS RO observations to upgrade E-PROBED to also include longitudinal variabilities not driven by photoionization. We will then evaluate the differences between conductivity variability calculated using E-PROBED and TIE-GCM E-region Ne as functions of geographic longitude, latitude, altitude, universal time, season, and solar cycle phase. The main deliverables are files containing tabulations of uncertainties in TIE-GCM conductivity ran under commonly used configurations. This proposed work addresses the science goal FST #1 to inform a first-principles model by quantifying the role of E-region Ne uncertainties on TIE-GCM conductivity. By providing these uncertainties, this proposed work specifically contributes to FST team efforts that involve using or comparing with TIE-GCM conductivity. This proposed work also contributes to the FST team's effort by investigating E-region conductivity variability and uncertainties due to processes beyond those driven by solar radiation.

References:

(1) Salinas, C.C.J., Wu, D.L., Swarnalingam, N., Emmons, D.J. and Malins, J., E-region Prompt Radio Occultation Based Electron Density (E-PROBED): An empirical model for operational applications, in preparation for Atmospheric Measurement Techniques' Special Issue
(2) Wu, D. L., Emmons, D. J., & Swarnalingam, N. (2022). Global GNSS-RO Electron Density in the Lower Ionosphere. Remote Sensing, 14(7), 1577.

Kareem Sorathia/JHU APL

Revealing Cross-Scale Geospace Coupling: The Nightside Transition Region and its Auroral Manifestations

Science Goals & Objectives:

During geomagnetically active periods, geospace behaves as a complex synergistic system with its domains coupled via a web of non-linear, cross-scale interactions. The nightside transition region (NTR), separating the magnetotail from the inner magnetosphere, plays a fundamental role in the system-level geospace response. Convection across the NTR brings energetic ions to the inner magnetosphere, creating the ring current and shaping the global current system that closes in the ionosphere. Conductivity in the nightside ionosphere enables this closure and is the result of energetic electrons transported through the NTR and scattered by waves. The nightside aurora is a reflection of these processes. Thus, understanding how multiscale dynamics in the NTR are manifested in the aurora is crucial to a complete picture of the geospace response during active periods. Developing this understanding is the primary goal of this proposal.

Despite decades of study, the connection between the NTR and aurora remains enigmatic. This is due to limited observations connecting magnetospheric processes to their auroral manifestation and, until recently, the lack of models capable of capturing the multiscale nature of the coupling. Indeed, NTR dynamics are known to be often dominated by mesoscale processes such as bursty bulk flows with typical cross-tail size of 1-3 Earth radii, while the corresponding auroral forms have typical scales of 100s of km. In the proposed project, we leverage recent advances in high-resolution modeling and multispectral auroral all-sky imaging (ASI), to reveal the magnetospheric drivers of mesoscale auroral forms and their relation to the dynamics of the NTR. The emergence of these observational and modeling capabilities creates a remarkable opportunity and makes the proposed project particularly timely. Specific objectives include: quantifying the role of mesoscales in coupling between the NTR and aurora and its variation with increasing geomagnetic activity; identifying the auroral manifestation of flow bursts and their braking; and identifying the auroral manifestation of plasmaspheric erosion, its driving factors, and how that shapes the wave environment.

Methodology:
To accomplish our goals, we combine modeling and data analysis. Our modeling efforts will utilize the Multiscale Atmosphere Geospace Environment (MAGE) model augmented with new capabilities: multifluid treatment of the inner magnetosphere, separating the ring current and plasmasphere; and a gray box model of diffuse precipitation which captures the shifting chorus and hiss domains as the plasmasphere evolves.

Our data analysis efforts will use THEMIS ASI and new multispectral imaging from the Transition Region Explorer (TREx). We will also utilize NTR-relevant spacecraft (e.g. MMS, GOES) and SuperMAG data. To facilitate comparisons between MAGE and ASIs we use the GLOW (GLobal airgLOW) model to calculate synthetic emission from model output and assimilate ASI data onto regular grids.

Relevance & Contribution to FST:
The auroral manifestation of the NTR is a system-level consequence of geospace coupling across disparate scales and plasma populations. Therefore the proposed investigation goes to the heart of the FST target of soliciting studies capable of 'extracting system-level information and insight'. Our investigation directly addresses FST Science Goals #1 and #2, the latter of which explicitly includes the connection between the ionosphere and the plasmasphere.

Beyond the core investigation we propose, our efforts will contribute to the broader FST. We will formulate a portfolio of events to simulate at high-resolution and conduct detailed ASI analysis of. The choice of these will be informed by the shared goals of the broader FST and will provide model output that can further those investigations; e.g. data that can be used as input to regional models or to augment the analysis of other data sets.

Edmund Spencer/University of South Alabama
Substorm Identification With The WINDMI Magnetosphere - Ionosphere Nonlinear Physics Model

Geomagnetic storms and substorms adversely affect satellite communication equipment in space, large electrical power distribution grids, petroleum pipeline networks and communication equipment on the ground by inducing electric and magnetic fields in the conductors. Solar energetic particles whose energies and densities are enhanced during storms cause operational problems for spacecraft and satellites by affecting the sensitive electronic equipment onboard. Identifying the onset of a substorm, which roughly speaking is centered around the time when the stretched magetotail abruptly transitions into a dipolarized configuration, is a subject of intense debate. There have been several substorm onset initiation criteria that have been developed, either from auroral observations (many authors), or from auroral electrojet features e.g. Forsyth et. al. 2015, Partamies et. al. 2013, Newell and Gjerloev, 2011, Maimaiti et. al. 2019. We will investigate the different criteria using a low order physics model of the magnetosphere called WINDMI. We will compare the model variables with the criteria for substorm onset proposed through examining the AL index, d(SML)/dt, or from observations of auroral brightenings and enhancements. By coupling the WINDMI model with a Deep Learning algorithm, we will force the combined system model to be consistent with satellite electric and magnetic field observations, and track the magnetotail energy dynamics, E X B plasma flows, the field aligned current contributions, energy injections into the ring current, and ensure that they are within allowable limits. The timing of onset for each event, the model parameters and the model intermediate state space variables will be examined and analyzed. We will compare the model variables and solar wind driven dynamics with the auroral observations, brightenings, and electrojet features. These observations will be synchronized with satellite observations in the magnetotail during substorm events using Deep Learning Techniques.

Tibor Torok/Predictive Science Inc.
On the Evolution of CMEs in the Corona and Inner Heliosphere

Science Goals and Objectives:

This proposal responds to the Focused Science Topic (FST) 3, "Evolution of Coronal Mass Ejections [CMEs] in the Corona and Inner Heliosphere", of NASA's LWS23 solicitation. Utilizing state-of-the-art magnetohydrodynamic (MHD) numerical simulations of idealized and observed CMEs, comparison to NASA spacecraft data, and sophisticated analysis tools, we propose to systematically explore the properties of the magnetic field in CMEs as they travel from the Sun to 1 AU. Specifically, we will:

- Perform idealized and case-study Sun-to-Earth simulations designed to elucidate key features of CMEs as they propagate in the solar corona and inner heliosphere and interact with the ambient medium;

- Use these simulations to investigate the structure and evolution of the magnetic field in CMEs, its interaction with ambient fields, and the formation, distribution, and role of electric currents;

- Compare synthetic satellite data obtained from the simulations to real data, to interpret CME observations and to evaluate model uncertainties and improve their accuracy.

Together, these studies will allow us to address open questions about CMEs, such as:

- How does the structure and connectivity of the magnetic field in CMEs change as they propagate from the Sun to 1 AU? Where and when does reconnection with ambient coronal and interplanetary fields happen, how much flux is transferred, and how does it affect CME evolution?

- What determines the distribution of electric currents in CMEs, how do those currents evolve over time, and how do the resulting forces affect CME evolution and space-weather-relevant properties such as their trajectory and magnetic orientation?

Methodology:

We will employ our Magnetohydrodynamic Algorithm outside a Sphere (MAS) MHD code to realistically model a set of observed CMEs, to be selected by the Focused Science Team. CMEs will be modeled by (1) producing a 'thermodynamic MHD' model of the corona using observed magnetograms; (2) energizing the CME source region with a customized flux-rope model that will be slowly driven to eruption; and (3) propagating the CME from the corona to 1 AU with the heliospheric module of MAS. This will allow us to produce synthetic EUV and white-light images and in-situ data from/at arbitrary viewpoints/locations, which can be directly compared to observations. Using such comparisons, we will evaluate model uncertainties and improve their accuracy. The case-study simulations will be supported by simpler 'polytropic MHD' runs using idealized configurations, for systematic explorations of the formation and distribution of CME electric currents. We will use advanced tools such as tracer particles, squashing-factor maps, and slip-mapping techniques to analyze in detail the evolution of the CME's connectivity to the Sun, the structure of its magnetic field, and flux transfer due to magnetic reconnection.

Relevance and Proposed Contributions to the Focused Science Team Effort:

By utilizing state-of-the-art CME simulations, the proposed research will connect the physics of the corona and inner heliosphere, supporting NASA's efforts to narrow the gap between remote-sensing and in-situ observations. Furthermore, it will significantly advance our physical understanding of CMEs, rendering it highly relevant to the scientific objectives of the FST 3. Our contributions to the Focused Science Team will mainly consist of (i) developing joint studies with the rest of the team to strengthen the overall effort and (ii) providing simulation data to other team members for, e.g., evaluation of observational analysis methods and comparison with other models. The proposed research is timely and aligns with the NASA/LWS Program goals to "(1) Understand how the Sun varies and what drives solar variability" and "(2) Understand how the Earth and planetary systems respond to dynamic external and internal drivers."

Daniel Welling/University Of Michigan, Ann Arbor

Determining the Importance of Meso- vs. Macro-scale Contributions to Ionospheric Conductance

There is growing interest and research concerning mesoscale processes in the magnetosphere-ionosphere-thermosphere (MIT) system. It has been shown that large scale dynamics may be modified or even dominated by mesoscale contributions. One example is many fast flow bursts in the tail building to dominate ring current injections. This is especially relevant for conductance, where large scale processes (e.g., contributions from the diffuse aurora accelerated in regions of upward field aligned current impinging upon a climatological neutral atmosphere), are augmented with precipitation from small-scale structures and dynamics in the neutral atmosphere onto which energy is deposited. The net result is a large scale, smoother conductance pattern that is punctuated by high conductance regions that will affect ionospheric and magnetospheric flow. This is clearly illustrated via images of the aurora, where the large-scale oval arises out of a harmony of arcs, beads, and other structures. Ionospheric conductance is critically important, as the macro- and meso-scale sources combine to control ionospheric electrodynamics, which, in turn, affect magnetospheric dynamics, ring current development, and other MIT phenomena. This description begs the question of the importance of the mesoscale contributions to ionospheric conductance. While mesoscale conductance features are certain to drive a localized response, do these features change the macro-level behavior of MIT system? Or, rather, is the behavior of the system best described by the macro-scale ionospheric conductance?

This proposal seeks to answer these questions by developing and employing an advanced, physics-based ionospheric conductance model to simulate the MIT system and compare to observations. The conductance model within the Space Weather Modeling Framework (SWMF) will be expanded such that pitch angle and electron energy information will be obtained via anisotropic pressure, electron entropy magnetohydrodynamics (MHD). Coupling between the Comprehensive Inner Magnetosphere Ionosphere (CIMI) model and BATS-R-US MHD will ensure accurate electron temperature within the closed field line region. Physics-based adaptive mesh refinement will be employed to capture a broad array of mesoscale processes in the magnetosphere that result in mesoscale precipitation features. Coupling to the Global Ionosphere Thermosphere Model will provide coupling to the dynamic thermosphere, further producing mesoscale structure. Ultra-high resolution simulations will be performed to capture the meso- and macro-scale conductance pattern. Simulations will be repeated with spatial smoothing applied to the ionosphere that will average over mesoscale features while retaining the total energy deposited into the ionosphere-thermosphere. Simulations will be compared to each other and observations in terms of precipitating fluxes, field-aligned and auroral currents, ring current development, and magnetospheric geometry.

The goals of this proposal are directly relevant to FST 1: Understanding Ionospheric Conductivity and its Variability. The simulations and analysis will make deep advances towards understanding the formation of ionospheric conductivity patterns at both small and large scales. Answering the main science question will reveal temporal and spatial requirements of conductance specifications as the community drives towards next-generation models. The groundbreaking modeling advances that will be performed in this study will be of great value to the overall Focus Science Team. As we employ these new advances to simulate events-of-interest, we will be able to provide the full team with modeled maps of precipitating average energy and energy flux to help place observations into a global context.